



Role of Soil Health in Plant Disease Management: A Review

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ABSTRACT

Soil health sustains the biological productivity, maintains environmental quality and promotes plant health. Soil borne diseases are most damaging when soil conditions are poor. Major factors influencing the disease in plants are soil moisture, soil temperature, soil pH and soil nutrients. To manage disease, different methods are used like crop rotation, biological control, cover crops, suppressive soils, organic amendment, plant growth promoting rhizobacterium, vascular arbuscular mycorrhizal fungi, mulching, good compost, good aeration, etc. Implementation of these practices improves the soil health and reduces disease incidence in a sustainable manner. Cover crops, crop rotations and healthy sanitary practices keep the pathogenic populations at low levels and also add beneficial nutrients like nitrogen, phosphorus and potassium to the soil. These all manage the disease by creating physical barrier, releasing antagonistic chemicals, competing with pathogen, increasing nutrient uptake, etc. Biological control agents have different mode of action viz., parasitism, predator, antibiosis, competition for site and nutrition, as well as by inducing the resistance in plants against pathogen [Induced Systemic Resistance (ISR)]. However, all these management strategies are helpful in improving the soil health, decreases the disease incidence and subsequently increases the yield and productivity of the crop.

Key words: Amendments, Antagonistic, Disease, Nutrients, Pathogenic population, Soil health.

Soil is the most important component for maintaining ecosystem balance on the earth. The relation of soil fertility and microorganisms for expression of better crop health, production and quality is well known. In rhizosphere, there are different microorganisms which directly or indirectly influence the plant health and growth development (Kamal *et al.*, 2015). Several diseases of field crops are soil borne and are considered a major limitation to better crop production. Soilborne plant pathogens such as *Rhizoctonia* spp., *Fusarium* spp., *Verticillium* spp., *Sclerotinia* spp., *Pythium* spp. and *Phytophthora* spp. can cause 50 to 75 per cent yield loss for many crops such as wheat, cotton, maize, vegetables, fruits and ornamentals (Baysal-Gurel and Kabir, 2018). The use of fungicides against soilborne plant pathogens can help to manage some diseases, in contrast, frequent and indiscriminate use can increase environmental and health concerns, and lead to development of fungicide resistance (Christopher *et al.*, 2010). Some environment-friendly approaches have been developed to manage the soil borne diseases while maintaining the soil health. In soil, microorganisms reside in rhizosphere and constitute a complex organization of endophytes, saprophytes and actinomycetes, both harmful and beneficial ones (Baysal-Gurel *et al.*, 2019).

Various strains of *Bacillus* species are known as potential elicitors of ISR and exhibit significant reduction in the incidence or severity of various diseases on diverse hosts (Choudhary *et al.*, 2008). It is believed that plants have the ability to acquire enhanced level of resistance against pathogens after getting exposed to biotic stimulation provided by many plant growth-promoting rhizobacteria (PGPR's) and this is known as rhizobacteria mediated induced systemic resistance (ISR) (Choudhary *et al.*, 2007). Arbuscular mycorrhizal fungi (AMF) can suppress plant pests and diseases through induction of systemic resistance (Jung

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et al., 2012 and Pineda *et al.*, 2010). Mycorrhiza-induced resistance (MIR) involves an ISR component elicited by bacteria in the mycorrhizosphere, as AMF, rhizobacteria possess MAMPs, which can trigger MAMP-induced immune responses (Berendsen *et al.*, 2012). Green manuring can play an important role in this regard as it showed versatile impacts like improvement of soil physio-chemical and biological properties, fertility, nutrient supply to succeeding crops, checking erosion and plant protection (Saini *et al.*, 2019). This review paper seeks to summarize the different methods used for management of soil borne diseases by improving soil health including mycorrhiza, cover crops, bioagents, mulching, good compost, good aeration, suppressive soils, nutrients, intercropping and crop rotation.

Soil health

Doran *et al.* (1994) defined soil quality (health) as "The capacity of a soil to function, within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health." It is worth noting here that "soil health" and "soil quality" are

essentially synonymous terms. Soil moisture, soil temperature, soil pH, organic matter, nutrients, beneficial microorganisms, organic amendments, crop rotation, cover crops and green manures are the various factors which influence soil health.

Soil moisture

Water contained in soil is called soil moisture. Optimum soil moisture is important for plant growth. There is a relation of moisture with diseases. Late blight of potato, apple scab, downy mildew of grapes and fire blight are favoured by high rainfall and high relative humidity. Most severe symptoms of *Phytophthora*, *Rhizoctonia*, *Sclerotinia* and *Sclerotium* can be observed on plants when the soil is wet but not flooded. In case of bacterial (e.g., *Erwinia* and *Pseudomonas*) and nematode infection, more severe symptoms are produced on plants when the soil is wet. *Streptomyces scabies* which causes the common scab of potato becomes more severe in soils drying out after wetting. *Fusarium roseum*, the cause of seedling blights, *Macrophomina phaseolina*, the cause of charcoal rot of sorghum and root rot of cotton and *Fusarium solani*, the cause of dry root rot of beans occur in dry environments. Verticillium and canker diseases of forest trees are more severe in water stress conditions (Agrios, 2005). Soil moisture and temperature have direct relation with seedling blight of wheat and corn (Dickson, 1923). We can manage all these diseases by maintaining the soil moisture level below or above optimal soil moisture required by the pathogen.

Soil temperature

Warm, moist soils with high levels of carbon to nitrogen ratio will have higher level of microbial activity and a relatively higher level of suppression. Soil temperature can greatly affect the activity of locomotion, infection and reproduction of nematodes. Some species of the fungi *Typhula* and *Fusarium*, which causes snow mold of cereals and turf grasses, thrive only in cool season or cold regions. Also, the late blight pathogen *Phytophthora infestans* is more serious in the Northern latitudes whereas in the subtropics it is serious only during the winter. Many diseases, such as brown rot of stone fruits caused by *Monilinia fructicola*, are favored by relatively high temperatures and are limited in range to areas and seasons in which such temperatures are prevalent. Several diseases, such as the Fusarial wilts, anthracnoses caused by *Colletotrichum* spp. and the bacterial wilts of solanaceous plants caused by *Ralstonia solanacearum*, are favored by high temperatures and are limited to hot areas, being particularly severe in the subtropics and tropics. At temperature much below or above the optimum for the pathogen, or near the optimum for the host, disease development is slower (Jones *et al.*, 1926).

Soil pH and soil structure

Soil pH is an estimate of the activity of hydrogen ions in the soil solution. It is also an indicator of plant available nutrients. High activity is not desirable and the soil may require liming

with base cations Ca or Mg in order to bring the solution back to neutral. Soil pH increases by adding lime while it decreases by adding sulphur and ammonium. The pH of the soil is important in the occurrence and severity of plant diseases caused by certain soil borne pathogens. For example, the club root of crucifers caused by *Plasmodiophora brassicae* is most prevalent and severe at about pH 5.7, whereas its development drops sharply between pH 5.7 and 6.2 and is completely checked at pH 7.8. Common scab of potato caused by *Streptomyces scabies* can be severe from pH 5.2 to 8.0 or above, but its development drops sharply below pH 5.2. Soil texture and structure could have effects on plant diseases because they affect water holding capacity, nutrient status and gas exchange as well as root growth. Poor soil aeration caused by poor soil structure, soil type or water logging is associated with the development of cavity spot (*Pythium* spp.) disease in carrot. The pea root rot complex (*Fusarium* spp.) is known to be affected by compaction, temperature and moisture of the soils (Chupp, 1928). All these diseases can be managed by maintaining good aeration or soil pH and avoiding waterlogged conditions.

Soil microorganisms

Microflora (bacteria, fungi, actinomycetes, *etc.*) constitute up to 75 to 90 per cent of the soil-living biomass and are the primary decomposers of organic matter. Two major components of microbial biota in soil are: a). Disease-inducing microbes: Fungi and bacteria can cause diseases to plants or degrade the soil quality by interfering with beneficial microorganism(s) thereby affecting plant health. Fungal pathogens like *Plasmodiophora brassicae* (club root of crucifers), *Spongospora subterranea* (powdery scab of potato), *Fusarium*, *Rhizoctonia*, *Verticillium*, *Phytophthora*, *Pythium* and *Sclerotinia* and bacterial pathogens like *Ralstonia solanacearum* (wilt), *Erwinia* sp. (soft rot) and *Streptomyces scabies* (potato scab) causes a great extent of damage to many crops. Soil-borne viruses also cause diseases such as *Lettuce big vein virus* (LBVV) and *Lettuce stunt necrotic virus* (LSNV). These soil-borne pathogens can survive in soil for many years (Saha *et al.*, 2016). b). Biocontrol agents inhabiting in soil (Resident biocontrol agents): Soil residing microorganisms (bacteria/fungi) are used successfully for controlling diseases. Disease control and better crop health can be achieved through various activities performed by these soil microbes like hydrocyanic acid (HCN) production, siderophore production, nitrogen assimilation, antibiotic production, hydrolytic enzyme (lipase, chitinase, *etc.*) production, induced systemic resistance and systemic acquired resistance. *Bacillus* spp. and *Pseudomonas* spp. serves as excellent examples of biocontrol agents having prominent PGPR (plant growth-promoting rhizobacteria) activities and disease reduction ability (Saha *et al.*, 2016).

On the basis of microbial activity of soil, it is a). Disease-inducing soils: are disease causing soil which means that pathogenic microbes comprise of 5 to 20 per cent of total soil microflora. When fresh organic matter is applied in this

type of soil, incomplete oxidized products are released, which are hazardous to plants and in turn, are easily attacked by pathogens or insects. Such soils can be amended into disease suppressive soils by addition of inoculum of effective microorganisms (Parr *et al.*, 1994). b). Plant growth promoting microorganisms (PGPM): exert direct effect on plant growth promotion *e.g.* *Rhizobium* and *Glomus* spp. Bacteria which possess the tendency to colonize roots actively are called as PGPR (Schroth and Hancock, 1982). For soil-borne pathogens and disease management, rhizospheric microbes emerged as a biological weapon that triggers the mechanism of disease reduction through Systemic Acquired Resistance (SAR) and Induced Systemic Resistance (ISR). Soil microflora facilitate uptake of nutrients from soil which results in enhanced yield as well as disease reduction or suppression. *Bacillus subtilis* has the potential in disease reduction and more than twenty antibiotics are produced by them. Efficacy of *Bacillus* spp. has been reported in different crop plants like tomato, chilli, brinjal *etc.* to control different pathogens like *Colletotrichum acutatum*, *C. capsici*, *C. gloeosporioides*, *Pythium aphanidermatum* and *R. solani* (Abdul *et al.*, 2007).

Antibiotic production

Rhizobacteria contributes in disease suppression with antibiotic production. There are six classes of antibiotic compounds (for which their modes of action are partly understood) that are related to the biocontrol of root diseases *viz.* phenazines, phloroglucinols, pyrrolnitrin, pyoluteorin, cyclic lipopeptides (all of which are diffusible) and HCN (Haas and Defago, 2005). *Pseudomonas fluorescens*-5 (Pf-5), source of pyoluteorin and pyrrolnitrin, was found to be effective in protecting damping off in cotton (*Pythium ultimum* / *Rhizoctonia solani*) (Howell and Stipanovic, 1980). Maksimov *et al.* (2011) reported majority of *Bacillus* spp. for the production of antibiotics such as polymyxin, circulin and colistin, which were found active against Gram-positive and Gram-negative bacteria and many pathogenic fungi. An antibiotic, Geldanamycin produced by *Streptomyces hygroscopicus* var. *Geldanus*, reduced the *Rhizoctonia* root rot of pea (Rothrock and Gottlieb, 1984). Similarly, HCN is a volatile compound and is useful in the biocontrol of diseases (Defago *et al.*, 1990).

Root colonization

The main aspect for biocontrol is the colonization of rhizosphere soil or external / internal root zone by microbes, especially bacteria (Bahme and Schroth, 1987). In biocontrol method, root colonization is completed in two phases: Firstly, bacteria get attached to rhizosphere and are then transported on the elongating root tip. Secondly, bacteria spread locally, proliferate to the boundaries of niche by competing with other indigenous microorganisms and survive. Root colonization involves recognition of pathogens by potential antagonists and it is important for base line of effective biocontrol strategies (Barak and Chet, 1990).

Induced systemic resistance

Induced systemic resistance (ISR) was explained and reported in carnation plant in which *Pseudomonas* strain (Pf WCS 417r) was found effective against *F. oxysporum* f. sp. *dianthi* (Van Peer *et al.*, 1991). Induced resistance is the ability of plants to develop an enhanced defensive ability when appropriately stimulated (Van Loon *et al.*, 1998). Some pathogenesis-related proteins (PRs) like 1, 3-glucanases and chitinases are capable of hydrolyzing fungal cell walls and insects (Singh *et al.*, 2015). *Pseudomonas* and *Bacillus* spp. are the most popular rhizobacteria encompassing ISR (Van Wees *et al.*, 2008).

Management of diseases by improving soil health

Different methods used to improve soil health and manage diseases are use of organic amendment, cover crops and green manures, beneficial organisms (bioagents), crop rotation, nutrient management, VAM fungi and suppressive soil.

Organic matter amendments

The addition of organic matter such as cover crop green manure (single and mixed species), seed meals, dried plant material, good quality compost, organic waste and peats can aid in reducing diseases caused by soil borne pathogens. Organic biochemicals are environment friendly, easily biodegradable and safe for humans. Organic matter thus is capable of restoring ecological balance *e.g.* Phytophthora root rot is suppressed by using composted tree bark. Verticillium wilt of tomato is decreased by using blood meal and fish meal. Organic manure supply nutrients which are suitable for antagonists, which favor them in competition. Soil amendments with plant materials help in management of root rot of apple. Fusarium crown rot of Chinese yam, cucumber Fusarium wilt are suppressed by application of pig manure and rape seed bio-organic fertilizer to field plots (Zhang *et al.*, 2008).

Green manuring crops

Cover crops are defined as any living ground cover that is planted into or after agriculture crops mainly cash crops and turned into the soil before planting next crop plants. Hartwig and Ammon (2002) stated that first benefit of cover crops is reduction of runoff and soil erosion which subsequently results in improvement of soil health and sustainable soil productivity. Cover crops also keep the soil moist, which is favourable for microbial activity. Cover crops also affects soil microbial biomass C and N of long term field. This control can come through direct suppression of the insects by the plants or by attraction of beneficial insects that prey or parasitize the pests.

Barley (*Hordeum vulgare*) suppresses leafhopper, aphids, armyworms, root-knot nematodes; buckwheat (*Fagopyrum esculentum*) attracts hover flies, wasps, minute pirate bugs, insidious flower bugs, tachinid flies, lady beetles that prey or parasitize aphids, mites, other pests; cowpeas (*Vigna unguiculata*) attracts wasps, honeybees, lady beetles,

ants that prey on crop pests; rapeseed (*Brassica napus* and *Brassica rapa*) suppresses plant parasitic nematodes; red clover (*Trifolium pretense*) attracts beneficial insects; rye (*Secale cereal*) reduces insect pest problems in rotations, attracts beneficial insects; sorghum-sudangrass hybrids (*Sorghum bicolor* x *S. bicolor* var. *Sudanese*) disrupts life cycles of diseases, nematodes; subterranean clovers (*Trifolium subterraneum*, *T. yanninicum*, *T. brachycalcycinum*) reduces pest egg laying and larval populations in cabbage, thrips in leeks, tarnished plant bug; sweet clovers (*Melilotus officinalis*, *M. alba*) attracts honeybees, tachinid flies, large predatory wasps; woollypod vetch (*Vicia villosa* ssp. *dasyarpa*) attracts beneficial insects (Brevik, 2009).

Intercropping and crop rotation

Intercropping and crop rotations promotes microbial multiplication and activities. Intercropping or polyculture is defined as the cultivation of two or more crops on the same piece of land to the extent that crops interact biologically. Such biological nitrogen fixation improves the fertility of the soil and both the soil health and quality as the availability of nitrogen positively affects the C: N ratios by increasing the N value. This in turn improves the general microbial ecology of the soil by allowing proliferation of diverse and increased number of soil biota. Growing crops in a planned sequence on the same field is known as crop rotation. The rotation of host crop with non-host crop plays an important role in managing diseases. Crop rotation is a key factor in residue management for disease control as it breaks disease cycle by reducing inoculum level i.e. some pathogens that cause disease, survives in soil for many years in the form of sclerotia, spores, hyphae. Monoculture encourages many soil borne diseases because the pathogen specific to a crop can multiply out of all proportions when that crops is grown in the same place year after year. The club root in brassicas requires a 7-year rotation. The diseases are easily managed by crop rotation as some pathogens survive on roots and leaves of taxonomically diverse weeds e.g. bacterial spot of pepper and tomato (*Xanthomonas campestris* pv. *vesicatoria*), bacterial speck of tomato (*Pseudomonas syringae* pv. *tomato*), root-knot nematode (*Meloidogyne hapla*), etc. There are certain pathogens that survives in soil and cannot be easily managed e.g. *Fusarium* wilts of crucifers, cucurbits, pea, spinach, tomato and *Rhizoctonia solani*. If legume crops are used in the rotation, nutrient cycling is improved through biological nitrogen fixation (BNF) by symbiotic rhizobacteria (*Rhizobium* spp., *Sinorhizobium* spp., *Bradyrhizobium* spp.). Similarly, free-living nitrogen-fixing bacteria (*Beijerinckia fluminensis*, *Azotobacter paspali*, *Azospirillum* spp.) associated with non-legume plants like sugar cane, maize, or rice contribute to BNF, explaining the productivity of these crops under low input management (Baldani and Baldani, 2005). AMF populations are favored when a cover crop like hairy vetch (*Vicia villosa*) or sorghum-sudangrass (*Sorghum* x *drummondii*), Arbuscular Mycorrhiza Fungi (AMF)-root-symbiosis increases phosphorus (P) uptake (Douds and Millner, 1999).

Nutrient management

Plants suffering a nutrient stress will be more susceptible to diseases, while adequate crop nutrition makes plants more tolerant or resistant to disease. Mineral nutrition can affect two primary resistance mechanisms: a) formation of mechanical barrier (e.g. thickness of cell walls) and b) synthesis of natural defense compounds (e.g. phytoalexins). There is a relation between disease and nutrients. *Fusarium* spp., *Plasmodiophora brassicae*, *Sclerotium rolfsii*, *Pyrenochaeta lycopersici* and the diseases they cause (root rots and wilts, clubroot of crucifers, damping off and stem rots and corky root rot, respectively) increase in severity when an ammonium fertilizer is applied. *Phymatotrichopsis omnivora*, *Gaeumannomyces graminis* and *S. scabies* and the diseases they cause (cotton root rot, take-all of wheat and scab of potato, respectively) are favoured by nitrate nitrogen. Phosphorus has been shown to reduce the severity of take-all disease of barley (caused by *G. graminis*) and potato scab (caused by *S. scabies*). Potassium reduced the severity of numerous diseases, including stem rust of wheat, early blight of tomato and gray leaf spot and stalk rot of corn. Potassium in high amount increased the severity of rice blast (caused by *Magnaporthe grisea*), corn gray leaf spot (caused by *Cercospora zeae-maydis*) and root knot (caused by the nematode *Meloidogyne incognita*). Magnesium increased the severity of corn leaf blight caused by *Cochliobolus heterostrophus*. Molybdenum reduced the severity of late blight of potato and Ascochyta blight of beans and peas (Agrios, 2005). Septoria glume blotch of wheat is reduced with the application of potassium and phosphorus (Gunifer et al., 1980).

Biocontrol agents

Trichoderma harzianum, *T. viride*, *T. hamatum*, *Gliocladium* spp., *Flavobacterium* spp., *Streptomyces* spp., VAM fungi (Vesicular Arbuscular Mycorrhizae), *Bacillus subtilis*, *Pseudomonas fluorescens* helps in suppressing the effect of pathogen and reduces the disease incidence. *Trichoderma* strains are potential biocontrol against several fungal phytopathogens. Several soil-borne antagonists are reported to control fungal wilt of tomato caused by *F. oxysporum* f. sp. *lycopersici* (Singh et al., 2013).

The biocontrol agents produce antibiotics viz., 2,4-diacetyl-phloroglucinol (*Pseudomonas fluorescens* F113) against damping off (*Pythium* spp.); agrocin 84 (*Agrobacterium radiobacter*) against crown gall (*Agrobacterium tumefaciens*); bacillomycin D (*Bacillus subtilis* AU195) against aflatoxin contamination (*Aspergillus flavus*); bacillomycin, fengycin (*Bacillus amyloliquefaciens* FZB42) against wilt (*Fusarium oxysporum*); xanthobaccin A (*Lysobacter* sp. strain SB-K88) against damping off (*Aphanomyces cochlioides*); gliotoxin (*Trichoderma virens*) against root rots (*Rhizoctonia solani*); herbicolin (*Pantoea agglomerans* C9-1) against fire blight (*Erwinia amylovora*); iturin A (*B. subtilis* QST713) against damping off (*Botrytis cinerea* and *R. solani*); mycosubtilin (*B. subtilis* BBG100) against damping off (*Pythium*

aphanidermatum); Phenazines (*P. fluorescens* 2-79 and 30-84) against take-all (*Gaeumannomyces graminis* var. *tritici*); pyoluteorin, pyrrolnitrin (*P. fluorescens* Pf-5) against damping off (*Pythium ultimum* and *R. solani*); pyrrolnitrin, pseudane (*Burkholderia cepacia*) against damping off and rice blast (*R. solani* and *Pyricularia oryzae*); Zwittermicin A (*Bacillus cereus* UW85) against damping off (*Phytophthora medicaginis* and *P. aphanidermatum*) (Pal and Gardener, 2006).

These biocontrol agents show either direct antagonism by mechanisms such as mycoparasitism / predation (lytic/some nonlytic mycoviruses, *Ampelomyces quisqualis*, *Lysobacter enzymogenes*, *Pasteuria penetrans*, *Trichoderma virens*, etc.) or mixed-path antagonism by mechanisms such as antibiosis (2,4-diacetylphloroglucinol, phenazines, cyclic lipopeptides, etc.) / lytic enzymes production (chitinases, glucanases, proteases, etc.) / unregulated waste products (e.g. ammonia, carbon dioxide, hydrogen cyanide, etc.) / physical or chemical interference (blockage of soil pores, germination signals consumption, molecular cross-talk confused, etc.) or indirect antagonism by mechanisms such as competition (exudates/leachates consumption, siderophore scavenging, physical niche occupation, etc.) / promoting plant growth and plant defense mechanisms [induction of host resistance (contact with fungal cell walls, detection of pathogen-associated, molecular patterns, phytohormone-mediated induction, etc.) (Kamal et al., 2015). These metabolites can be either combined with appropriate biocontrol strains in order to obtain new formulations for use in more efficient control of plant diseases. Buckeye rot of tomato caused by *Phytophthora nicotianae* var. *parasitica* is a serious threat to the crop production. In investigation, six biological control agents were screened for the efficacy against mycelial growth of *P. nicotianae* var. *parasitica*. Out of the six fungal and bacterial biocontrol agents tested, *Trichoderma virens* resulted in maximum mycelial growth inhibition (77.67%) of the test pathogen followed by *T. hamatum* (69.40 %), *T. harzianum* (68.52%) and *T. viride* (67.43%). *Pseudomonas fluorescens* and *Bacillus* sp. were least effective with 53.67 per cent mycelial growth inhibition (Sharma et al., 2018).

AM (Arbuscular mycorrhizae)

AM is symbiotic association between a fungus and a root of higher plant. The most important nutritional effect of AM fungi is the improved uptake of immobile nutrients, especially P, Cu and Zn. AM fungi is associated with enhanced chlorophyll levels in leaves and improved plant tolerance to diseases, parasites, water stress, salinity and heavy metal toxicity. Cover plant roots, forming mat protect plant roots from many diseases in several ways by either providing physical barrier, antagonistic chemicals, competing with pathogen, or increasing nutrient uptake. AM mycorrhizal fungi physiologically alter the host competition with pathogen for space or host photosynthate. Nutritional benefits improved by mycorrhizal symbiosis, as well as induced biochemical alterations of the plant, by which VAM mycorrhizal fungi reduced soil borne diseases. The antimicrobial substances produced by the extraradical mycelium of the AM fungi species

Glomus intraradices reduced conidial germination of *F. oxysporum* f.sp. *chrysanthemi*. Co-inoculation of groundnut with *Glomus fasciculatum*, *Gigaspora margarita*, *Acaulospora laevis* and *Sclerocystis dussii* eliminated the damaging effects of *Sclerotium rolfsii*. *Glomus mosseae* prevented infection of soybean plants against *P. syringae*. *P. cinnamomi* was managed by *Glomus* sp. in avocado (Davis et al., 1978), *Dematophora necatrix* was managed by *Glomus* spp. (Bharat and Bhardwaj, 2001) and *P. cactorum* managed by *G. intraradices* (Utkhede and Smith, 2000) in apple and pathogen *Rhizoctonia* sp. was managed by ectomycorrhizal *Suillus granulatus* in *Pinus excelsa* (Corte, 1969).

Compost

Compost is used effectively in nursery, high value crops, potting soil mixtures for control of root rot diseases. Compost act as a food source and shelter for the antagonists that compete with plant pathogens. Two or more common beneficial biocontrol agents (strains of *Trichoderma* and *Flavobacterium*) were added to compost for suppressing *Rhizoctonia solani*. There is a direct relationship between compost level of decomposition and its suppression of *Rhizoctonia*. *Trichoderma harzianum* acts against a broad range of soil borne fungal crop pathogens by producing antifungal exudates. Immature compost, raw manure is conducive to diseases at first and becomes suppressive after decomposition.

Mulching

The proper mulching improves bulk density of soil, saturated hydraulic conductivity, soil moisture, soil temperature and consequently soil functions and improvement in biological activities. Zhang et al. (2008) reported abundance of earthworms under wheat straw mulch field as compared to non-mulch field. In addition, mulching increases the total carbon in bulk soil and helps to conserve moisture, control surface erosion and reduce airborne particulates (Karlen et al., 1994).

Disease suppressive soils

Soil population comprises of microbes that suppress the activity or growth of phytopathogens without any chemical usage (Timmusk, 2003). This ability is naturally borne by the soil, which is actual functional site (antagonistic activity) for beneficial microbes (Weller et al., 2002). Antagonistic microbes like *Trichoderma*, *Penicillium*, actinomycetes, etc. are the inhabitants of such soils producing sufficient amount of antibiotics, which restrict soil-borne pathogens like *Fusarium*, *Pythium*, etc. Plants cultivated under such soils are healthy and rarely infected with diseases or attacked by insects. The mechanisms viz., induced resistance, direct parasitism, nutrient competition, direct inhibition through antibiotics secreted by beneficial organism are involved in disease suppressive soils. There are two types of suppressive soil a). General suppression (non-specific, against many pathogen): termed as the widespread but confined ability of soils to inhibit the activity or growth of soil

borne pathogens. It can as well be termed as nonspecific antagonism or biological buffering (Weller *et al.*, 2002), e.g. *Phytophthora* root rot of papaya was managed by planting papaya seedlings in suppressive soil by putting in holes in the orchard soil that was infested with the *P. palmivora* (Rani and Sudini, 2013); b). Specific suppression (one organism operates against only certain types of pathogens): arises from a direct inhibition of a known pathogen by one organism. There are incidences where an agent of biological control is introduced into the soil for the specific reduction in occurrence of the disease. Specific suppressiveness owes its activity to the impacts of individual or select groups of microorganisms. Specific suppressiveness has been described for Fusarium wilts, *Gaeumannomyces graminis* var. *tritici*, *Phytophthora* spp., *Pythium* spp., *Rhizoctonia solani* and *Thielaviopsis basicola*. In take-all suppressive soils (*G. graminis* var. *tritici*.) activity of certain antibiotic-producing fluorescent pseudomonas or parasitism by *Trichoderma* spp. resulted in disease suppression. Production of antibiotics including phenazine-1-carboxylic acid, 2,4 diacetylphloroglucinol (2,4-DAPG), pyoluteorin and pyrrolnitrin played an important role in the biological control of this soil borne pathogen by certain strains of fluorescent *Pseudomonas* spp. (Berendsen *et al.*, 2012).

CONCLUSION

Many soil borne diseases are most destructive to crop production as these reduces the crop performance, decreases yield and results in higher production costs. Therefore, soil health represented by soil edaphic factors like moisture, pH and temperature plays an important role in management of plant diseases. High cost of chemical fungicides and development of fungicide resistance, climate change, new disease outbreaks and increasing concerns regarding environmental as well as soil health are becoming necessitates the quest for alternative suitable management options. Healthy soils do not allow the heavy build-up of pathogenic micro biota keeping their populations below the economic injury levels. So, we can manage many soil borne diseases by improving the soil health. Soil is also a home for many beneficial organisms like PGPR, VAM, bioagents (antagonistic fungi and bacteria) which are required to combat the attack of pathogens. Cover crops, crop rotations, mulching, suppressive soil, good quality compost and healthy sanitary practices keeps the pathogenic populations at low levels and also add beneficial nutrients like nitrogen, phosphorus and potassium to the soil. This all helps in providing systemic resistance to the crops, reducing the disease incidence and crop yield loss. It can be thus concluded that as healthy mind resides in healthy body, same way healthy plants reside in healthy soil.

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